INDUSTRIAL APPLICATIONS OF SMALL COMPUTERS

A Review

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Introduction

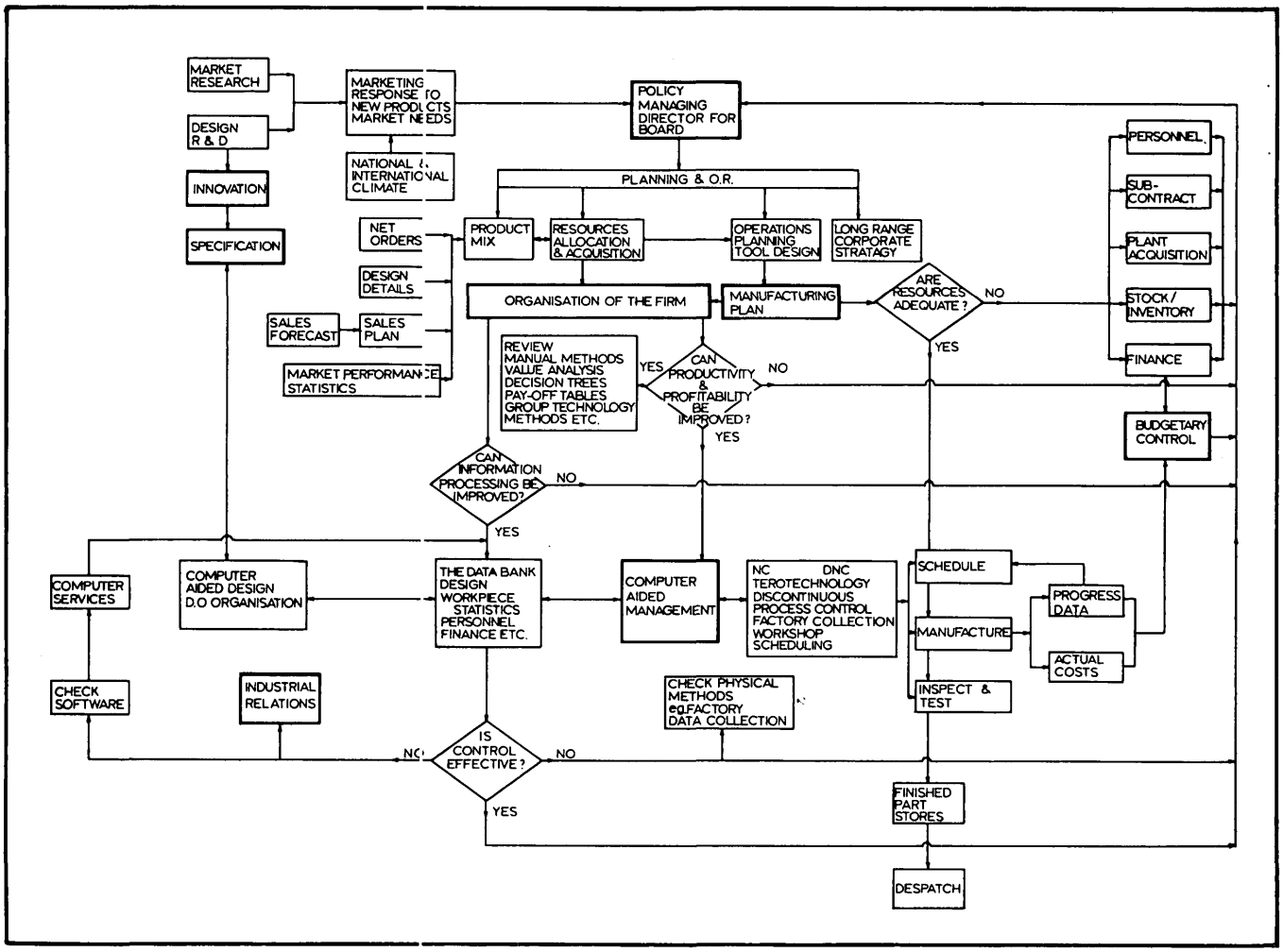
Small computers are being used increasingly in industry for a variety of tasks ranging over for example design, process control, automated inspection, R & D, machine-tool control, production control, assembly, preventive maintenance and warehousing. Whilst the potential applications are legion, the major application till now, has been the control of continuous processes. This is well documented[1,2] and will be referred to only briefly in this paper which will be concerned more with programmed automation of batch and mass manufacture in the metal-working industries rather than chemical, steel, paper making and the like.

The motivation for increased use of small computers in shop floor automation may come from labour shortages, particularly in areas of harsh environments, from changes in work patterns occasioned by a shorter working week or simply from a progressive improvement in methodology and increased quality control.

To explain in general terms the potential use of computers in the functional pattern of a firm's behaviour, I have produced the organisation chart in Fig. 1. This organisation chart is orientated to fairly deep involvement with the computers in the long run but is capable of segmentation and growth from small beginnings. The importance of the small machine in this context is that computer-based automation is not dependent upon the acquisition and availability of a large centralised machine nor is it therefore the prerogative of the medium to large firm. The chart, which resembles a logic flow diagram, identifies prime function (in heavy outline), major flows of money, work and information for financial manufacturing and management activities and for principal decisions and questions.

Such an organisation can exist in various hierarchies of large and small computers and data stores with a range of input/output devices; the choice is large, tape readers, visual display units, various factory data collection terminals, teletypes and graph plotters in the main.

Fig. 1. Management functions of the firm; computer based



The small computer can exist in a stand-alone mode connected to a dedicated input/output device. It can be used as an intelligent front-end terminal to a larger computer, or be connected one to another. It can be dedicated to a particular process uniquely or in control of several. It can act as a monitor or controller or both. It can be primarily a device for acquiring data for management to mull over or be interactively a part of an automated work-scheduling process. It can be used off-line, in-line and in real-time[3].

Characteristically, the usefulness of the small computer lies in its flexibility. Its hardware and software can be updated quickly and cheaply without adding much to the overall system cost or overhead. A large range of applications are possible and it permits decentralisation.

As with larger machines there has been a marked reduction in costs of small computers over recent years whilst capacity has increased; this trend is expected to continue[2]. To illustrate this the average number of circuits in a mini-computer, which was about 2,000 in 1965–66 using transistor technology, will become about 20,000 in 1980 using large scale integration (LSI) chips.

The production engineer as a potential user of small computers has to take a number of factors into account in his estimates of future costs and utility. He has to specify process parameters as they exist, and this includes a specification of the system to be replaced including data collection and how these are to be modified by the inclusion of the small computer. For example what new transducing and interface circuitry is needed; what data format is required as input/output; what specialist staff are required; is there a harsh mechanical and/or electrical noise background? The Electrical Research Association, one of several expert consultancy organisations, have suggested a series of basic questions of this type[4]. They or the National Computing Centre, National Engineering Laboratory, SCICON[5] and others, including the manufacturers of small computers, will advise. The choice open to the production engineer in the UK is remarkably large; there are about 60 varieties of small machines available from some 44 manufacturers. In the USA the number of manufacturers is nearer 70. About 50 to 75 per cent of total sales are for incorporation in larger instruments or control systems where special terms are negotiable. In the USA over $700m worth of mini-computers were sold in 1973, representing a growth of 50 per cent over 1972. The mini-computer market is expected to expand by over 20 per cent per annum[6].

I have not attempted to define 'small' in terms of size or cost in this paper; there are many references[4,7,8] which adequately deal with this aspect. By this time most production engineers have a good idea of what they understand by the term.

Applications

Small computers can be exploited by firms large and small. For larger firms they can expedite shop-floor operations while smaller firms can become computer owners instead of using computer bureaux, thereby developing familiarity and confidence. The relative convenience, economics and capability of an in-house small computer system versus a bureau cannot be dogmatically predicated; it is very much a matter for the individual small firm to decide in the light of the particular function to be performed. Nowadays the small computer can undertake tasks which were carried out on larger machines eg a company with as few as 25 employees can afford a computerised pay-roll or job-costing system[9].

The application areas refered to are:

- Machine tools
- Design
- Quality assurance
- Automatic control of continuous processes
- Control of discontinuous processes
- Automated assembly
- Factory management
- Factory data collection
- Terotechnology
- Industrial R & D.

Machine tools

The trend in machine-tool technology is towards increased automation and to a lessening of direct human involvement in the cutting process. This began with NC in the early 1950s in the US and progressed slowly, but is continuing to progress in spite of the recession of 1971–72 and current difficulties. It is now at the stage when the hard-wired machine control unit is being replaced by a small computer and hierarchical systems are being investigated[10]. The next extension of Computer Numerical Control (CNC)[11] will be to multi-machine working[12] where the financial investment can be extended over several machines and the labour content of the metal-cutting process reduced. This multi-machine CNC mode of working metal-cutting machines can have several extensions both on individual machines or to groups of machines, such as adaptive control and factory data collection.

Human adaptive processes can be replaced by adaptive control whereby the environment of the cutting process can be optimised to obtain the most favoured feedrates (say), giving lower cost cutting tools and better machine utilization. The mode of control can be by sensing a parameter such as cutter load directly by measuring spindle deflection (and horsepower); and then adjusting feedrate override of the NC unit to change the feedrate on an infinitely variable basis. Such a design is employed in the US MACOTECH MAC I adaptive control system which NEL is evaluating on Milwaukee-matic Ea and CIM-X milling machines. The software exists as an APT pre-processor which optimises metal removal with respect to the parameters of cutter size, material type and hardness, type of cut and machine-tool characteristics.

Benefits claimed by MACOTECH are 40 per cent average reduction in machining time on steel and about 35 per cent on aluminium; cutter life may be increased by 50 per cent for steel, but not for aluminium; more parts per hour; machine, cutter, part and fixture protection; reduced scrap and cutter breakage; reduced part programmer time; and reduced tool tryout time.

An extension of the indirect method of processing the cutting data is to use a computer in the loop as in CNC and let it also compute cutting conditions on-line. Bendix[13] have evolved such a system which they call 'trainable'. A further extension is advocated by Frost-Smith[14] in which cutting parameters are monitored and processed through a small CNC computer and then further processed in a work-scheduling program.

The term Direct Numerical Control (DNC) is used to describe systems of some complexity where a number of different machine tools and their management functions are controlled by a large computer, possibly interfaced by CNC computers on the shop floor acting as front-end processors and buffers. A few complex DNC systems exist and few simple factory data terminals (FDC) which can be incorporated into larger systems. With DNC and multi-machine CNC, FDC and machine-state reporting can be handled by the CNC computer by adding the necessary terminal device such as teletype and providing the software. NEL has included this option in its CNC system software.

It is possible for a firm to evolve a DNC system from relatively modest beginnings using CNC machine tools, adding, retrofitting and integrating existing NC machines and production control and operation planning facilities. The computer aided design (CAD) option of NC graphics wherein part programming control data are produced interactively using a graphics terminal and used to drive an NC machine tool directly in real time or after a storage interval is within our grasp. It can be argued that a far greater increase in productivity may be obtained by improving the management of the machine shop than by increasing the utilisation and availability of the machine tool itself (or by making them cheaper to buy); this argument does not invalidate the need for CNC or DNC which make their own contribution to improving productivity.

The cost of the small computer in a CNC machine tool is already relatively small and, as has been explained, it can be shared over several machines. A typical CNC cost for one

machine tool might be £5,000, excluding servo drives, transducers and other machine components, which is currently the price of one hard-wired controller and that for DNC £10,000 to £15,000, in comparison a programmable controller costs £1,000 to £1,500. An interesting side-efect claimed for CNC is that it has indirectly reduced the cost of conventional hard-wired NC controllers.

CNC computers are small general-purpose machines with basic software and the capability of handling terminal devices. Where adaptive control is likely to be added a floating point arithmetic capability must be incorporatable without disturbing the basic configuration. In multi-machine working the software must incorporate time-sharing one or more machine tools simultaneously with all control data in computer storage. Control tape editing may be needed whilst machines are operating.

The Herbert Machine Tools Batchmatic has an interesting employment of a small computer as a replacement for a hard-wired controller. Developed wholly in the UK, it represents an outstanding piece of courageous technological confidence on the part of UK industry at a particularly depressing time in 1971–72 for the machine-tool industry[15]

Some idea of price can be obtained from Data General's announcement regarding CONTOUR I, a CNC that can control two NC machines as far as 300 m from its 8K NOVA mini-computer at a price of $23,100, less than $12,000 per machine. The two machine extension appears to be the most immediate development of CNC and as 80 per cent of metal cutting is by lathes it is likely that the largest future market is to multi-machine CNC lathe operations.

The American Machinist[16] predicted that as much as 50 per cent of NC machine tools sold in the US in 1975 would be computer controlled. Currently only about one per cent of machine tools in the US are NC and a similar ratio exists for the UK. Clearly NC's progress has been very slow and considerable scope exists for its further adoption. Historically then, the change from conventional hard-wired NC to computer control cannot be significant. In the same way, the considerable progress and debate over NC languages of recent years is insignificant.

The sophistication of NC languages is exampled by NELAPT[17], available from NEL, and the US United Computing Corporation's UNIAPT small computer implementation of APT, which typically costs about $75,000 for a full capability fast system for a 16K 16-bit computer, a two and a half million 16-bit disc, tape reader, tape punch, card reader and line printer or between $33,000 to $58,000 for lesser systems[18]. These costs, plus those for the machine-tool post-processor and maintenance, show that the total system cost including all peripherals is substantially greater than that of the small computer alone but nonetheless small when discounted over a number of years (£6,500 per annum for a five year life). There is as yet no evidence to establish if bureau-based part programming on-line is cheaper than that using stand-alone systems.

Design

Design has a far greater effect on the cost of the product than the manufacturing process itself. The designer can also influence indirect labour costs in procurement, planning, scheduling, despatching, order control and stocking by as much as 65 per cent. By 1983 we can expect to see mini-computers in most drawing offices[19].

What goes on in most drawing offices is still rule of thumb, update of past experience, a considerable amount of work of necessity based on codes of practice and standards, and evaluation of algebraic formulas. Much of this is clearly tedious, time-consuming and wasteful of a good designer's time. A survey by Urwick Technology Management Ltd for Mintech (August 1970) of computer aids for design in the engineering industry concluded that future use of CAD by small firms did not lie with expensive hardware and sophisticated techniques. Small firms need outside help to identify the opportunities for CAD which should lead to improved productivity, reduced lead time, improved design and improved accuracy in the preparation of estimates. NEL and the CAD Centre at Cambridge provide this help.

The need for information storage and retrieval systems for parts already designed and for bought-out materials and supplies was also emphasised in the Mintech survey. At that time it was suggested that the high cost of automatic draughting equipment and of interactive graphics restricted their use. Since then the cost of minimal systems has decreased markedly and the trend is towards the use of draughting machines controlled by small dedicated computers.

Many recent small desk-top calculators are really special-purpose micro-computers. The computer has common storage and the same instruction set for both program and data. In contrast the calculator has distinctly separate storage for program and data. The computer typically has low level software which can be used to operate on the data or program—thus skilled programmers are needed—whereas the programmable calculator uses high level language, virtually eliminating software design content[20].

Typically the desk-top small computer/programmeable calculator will have available an intermediary level language, such as BASIC, an alphanumeric keyboard and a display with a built-in cassette memory. It can be used in conjunction with a modem on a terminal to a remote computer. The calculator memory is expandable by adding user read/write memory and plug-in ROM (read-only memory) with special ROM for manipulation of alphanumeric characters and matrix arithmetic thereby giving a conversational capability. Such a machine will cost about £3k to £5k with perhaps an additional £1·5k for a printer.

The price of computer graphics is at last showing signs of significant reduction. A 16K computer as a fully interactive light-pen system complete with keyboard, teletype with paper tape reader and punch can be bought for £10k and for another £2k a linked dual-cassette storage and reader can be added. Software is usually the basic assembler with BASIC or FOCAL as a higher level language.

Quality assurance

Quality assurance is aimed at ensuring that the design specification is properly interpreted during manufacture. It is evident that these activities can be costly and time-consuming.

Watkins[21] in his description of the pioneer work at Raleigh Industries on computerised inspection identifies two pressures on factory quality control/inspection departments: the collection of more data, more rapidly; and the requirement to reduce the direct expenditure on inspection, the aim being to obtain greater adherence to design specification, leading to less scrap and rework.

Ferranti Ltd, Dalkeith,[22] is well known for progressively improving the process of automatic inspection of machined components. One way of reducing set-up requirements, and the time required for inspecting complex components, is to employ an inspection machine. Even greater savings are possible when the inspection machine is linked to a dedicated small computer which can handle the relevant data quickly, performing calculations, comparisons, and statistical analyses from which product processes can be controlled.

A comparison of average inspection times for manual and automated inspection of a range of components having a Ferranti machine with and without an 8K PDP-8/e computer shows respective improvements of 80 and 100 per cent over manual methods. Several typical examples of different modes of computerised inspection and in-process monitoring were shown at the 1970 Chicago Machine Tool Exhibition. These included a Browne and Sharpe set-up of a Hydrocut vertical machining centre combined with a Validator 100 co-ordinate measuring machine for the checking of non-mathematical contours, using a PD-8/e computer to optimise incremental data (including conversion to linear or circular interpolation), which is then part-processed and transmitted to the machine-tool controller. Feeds, speeds, tool selection and other functions are input by teletype. The system can be used to inspect one workpiece whilst the next is being machined from a stored program. A similar system for the digitising-contouring of surfaces not easily described mathematically was shown by Cincinnati Milacron. It used a 406 mm (16 in.) Hydro-Tel profile miller with Acramatic IV NC system, an electronic tracer and a small computer with

the usual I/O devices. The tracer probes the prototype surface and the machine-tool slide position-sensors measure co-ordinates which are transmitted through the NC system to the computer, which produces a paper tape.

The development of huge electronic, mechanical and electromechanical systems (computers, missiles and rockets, military systems) has meant that their testing is commensurately sophisticated. Testing covers both development and production, and the test apparatus must be adaptable to meet the unique requirements of a project, and be capable of use by semi-skilled personnel with little fault-finding skill of their own[23,24]. Tests must ensure that production meets specification; they must yield statistical data from which working parameters may be calculated automatically. Comprehensive reviews of the subject are given in references[25, 26].

Many of the larger firms in the UK have established quality assurance laboratories and test houses, not only for their own purposes but also to provide a service to others.

Automatic control of continuous processes

The computer has been applied[27] for some time to continuous process control—the measurement and control of the manufacture and flow of materials—in large industries such as steel, petro-chemicals, smelting, paper, sugar and cotton. It has been argued[28] that with reduced prices and increased reliability the application of small process control computers in small industries will be equally profitable, and moreover, will provide indispensable management information.

Thomas[28] describes the types of computer control in the process industries as:

Supervisory—information from the process is used by the computer to issue printed instructions for manual adjustment of plant.

Analogue with set-point adjustment—in which the computer adjusts the set points of the analogue process controllers.

Direct—in which signals are provided to adjust controllers directly: this type is highly dependent on the quality of control instrumentation available.

The programmeable computer, as distinct from the special-purpose controller, should be adaptable to changes in requirements, and permit some degree of process optimisation and simulation at the design stage. Incorporation in larger systems also permits integration of the control of several closed-loop processes leading to a management information system. The extent of permissible management decision-making is one of the fascinating aspects of integrated process control—when and by how much should a manager be allowed to exercise control on the system in the short term as distinct from his needing information for long-term corporate strategy? In the UK today the range of continuous-process computerised control is extensive in sophistication (and cost), ranging from simple data-logging of performance to embryonic integrated systems. Oughton[29] has pointed out that the digital computer used in process control can operate many hundreds of control loops but he comments that it is not simply this feature that attracts the use of a digital computer but the flexibility for developing, improving or changing and the scope to do things for which the conventional analogue control devices are unsuitable. Use of the (large) computer itself to simulate the plant at the conceptual stage is likely to be extensive[30] when national expertise is more readily to hand. This area of engineering is not likely to be less demanding in spite of its historical start on others.

Amongst UK companies specialising in continuous control of industrial processes are, Plessey, Ferranti, Elliot Automation and Kent Automation Systems[8]. Ferranti's CP6 offers digital control at a cost comparable with conventional controllers together with operations management control, e.g. alarm monitoring[31].

Control of discontinuous processes including automated assembly

One of the most fascinating areas of small computer use is in the monitoring and control of sequential industrial processes where discrete components are manufactured and assembled. The controlling function derived from in-process measurement may be exercised through simple comparators, special purpose logic or an on-line small computer. To distinguish this work generally from systems developed for the process industries the term 'discontinuous process control' has been coined to describe the logical sequencing and synchronisation of a series of discrete events including the automatic measurement of weight, size, surface finish, cracks and holes[33].

There are few examples to date. The most advanced monitoring system reported[34] appears to be at Chevrolet-Saginaw which because of its apparent sheer size and complexity but, in reality, simple function monitoring, is worth detailing. Some 20,000 disc brake assemblies are produced per day (later 40,000 per day). The system uses 21,000 limit switches, 45,000 relays monitored through a ladder of 17 computers; there are 37 conveyor systems, 15 coolant systems, 13 chip blowing systems, 225 machine tools with a total of 1,707 stations and 1,900 employees. Computers in the system include one PDP-10, two PDP-15/30's, a PDP-8/e, a PDP-8/I (all DEC) and 12 Westinghouse P2000's.

The manufacturing plant is modular in nature: American Machinist says,

'Throughout the change, production continued. Employees and their wives (or husbands) were kept informed of the plan and more than 9,500 hours have been spent in training people for the requirements of the new system. During the transition employment has increased from 1,200 to 1,900.'

This is evidence of the need to consider industrial and social aspects, see also reference [35].

The control system for the plant consists of a material-director system and a materials monitoring system. The system is essentially for management information and is a network feeding into a data-routing largish PDP-10 (64 K) computer. Control is not automatic in the sense that manual decision-making is dispensed with—the status of the plant is reviewed every 0.1 second.

Machine information is collected at three levels. Mode I information includes part counts, rejects, whether a machine is cycling or down, and cycle times. Mode 2 is a diagnostic routine used when a fault is developed in the Mode I checks. Typically it will print out on teleprinters in the service department the last 20 diagnostic checks. Mode 3 is a preventive check which times certain motions, looking for undertime or overtime conditions that foretell trouble. There is no monitoring of tool condition or of tool life. Most of the machines have the familiar tool-cycle controls, which flash a blue light when it is time to change tools.

The visual centre has a panel that represents each machine with four indicator lights per machine: green, producing parts; white, cycling but not producing parts; red, not running; amber, assistance request. Each machine has three telephone jacks: one for the visual control centre, one for the maintenance-dispatch centre, and one for talk from machine to machine.

Automatic fabricating machines with hard-wired logic have been in use for some time. Replacing hard-wired logic by a mini-computer offers advantages; foremost is flexibility (program variables can be changed by keyboard request so that the machine then performs different jobs or accommodates different patterns). In a typical hierarchy of distributed mini-computers on the shop floor, supervised by a larger housekeeping computer, the mini-computers are data terminals as well as local controllers for the fabricating machines. In the manufacture of coils at Western Electric (USA) the substitution of mini-computers for hard-wired logic reduced the rejection rate to zero. Costs to WE from General Automation were on a fixed fee basis, and included a feasibility study and a detailed specification followed by flowcharts and programming; hardware construction, simulation using WE equipment and installation were also accomplished in a total time of 4 months[36].

Automated assembly is still in its infancy and its potential has not yet been established. It may await computer control of the type described. A comprehensive review of automated assembly was given recently by Iredale[37] in which he

predicts a move away by development effort from manufacture to assembly. He refers to Delphi prediction by NEL and to the use of robot manipulative devices. In the UK advanced research is being conducted into robot handling devices using small computers at Edinburgh, Warwick and Nottingham Universities[38]. Proprietary robotic manipulative devices using small computers are already available.

Factory management

The number of examples of reported factory management information systems that use a small computer is small, and are primarily concerned with production control. A typical installation is that a Serck Audco Valves, a firm well known for its pioneering work in the UK on group technology[39]. This is a typical UK medium-sized firm of about 1,000 employees, with a turnover of £4m, producing some 2,000 finished products using 15,000 individual piece parts and raw materials. The number of different parts per product varies between 5 and 200. Serck Audco's ICL 1901 with four 20kHz tape decks covers the functions of stock control (up-dated fortnightly for each machining cell), material control, foundry stock and production program purchasing reports, and listings for control committee decisions. It is interesting and confirms each firm's uniqueness that the ICL PROMPT package had to be tailored by Serck Audco to its requirements. Serck Audco's first objectives were simply to reduce the clerical work and cut down the operating cycle, by combining computerised production control and group technology to casting, machining and asembly processes. The firm has found that output has nearly doubled whilst the number of employees has decreased, with a corresponding reduction in stocks and work-in progress, followed by reductions in the manufacturing cycle time of 5 to 12 weeks (see Table 1).

A computer-based management information system[35] has been introduced by J. Goulder and Sons Ltd, which employs 180 people. The system is based upon a small local Friden computer at the firm and a larger computer at Huddersfield Technical College—the system could however be accommodated on a small computer. Comments made by the firm were that its approach to computerised production control was to set-up a working party (with delegated tasks) comprising managing director, works director, financial director, production controller, office manager, production manager, and representatives of Huddersfield Technical College, Elliott and Friden. All who had to work the system were involved from the outset, including the trade unions. Initiation and continuing support came from top management, not from O and M or systems analysis. Implementation of such systems involved novel thinking at the top of the management structure.

Geier comments[40] that Norway, Germany and Japan are leading the way in developing the integrated manufacturing system (IMS) in three steps:

(*a*) the development of computer numerical control,
(*b*) the development of multi-station computer-controlled manufacturing systems, and
(*c*) most important, the development of integrated manufacturing software systems.

The concept of the IMS is seen as a workable approach for applying the computer to the automation of the flow of information, for the planning and control of manufacturing activities and for the design and use of hardware compatible with such software.

Commander Hopper[41] has suggested that the linked small computer will emerge to displace giant computers in the next five to ten years, the bigger machines being confined to number crunching. Payroll, sales accounts and stores movements will be handled by small computers operating in a dedicated mode and transmitting necessary data to each other and to the management information small computer, each one having its own architecture and operating environment. Security of files against unauthorised access should be enhanced by using small computers. It is difficult to generalise about future factory organisation, as much will depend on the peripherals and interfaces needed as well as the size and extent of the data files.

Factory data collection

It is a pre-requisite to the use of a small or large computer in a factory environment that there be a collection system that feeds it 'clean' data and that the shop floor manager is involved in the system design. Application studies have shown that straightforward mechanisation of existing procedures will not provide the best economic solution. Furthermore, the data collection system, once established, must be allowed to deal with exceptions, these should not be dealt with manually. It is unlikely that any standard systems application package will ideally satisfy a user—it has to be tailored to the firm's requirement.

One of the pioneers of this subject in the UK has been Feedback Data Ltd which has now co-operated with Digico Ltd to produce a factory data collection system to perform such tasks as order processing and progressing with stock level monitoring. These systems use standard Feedback Data terminals operating directly into Digico Micro 16 V computers complete with mass storage devices, printers and visual display units. A typical system which provides a complete production control stock level monitoring and labour cost control facility for a company employing about 400 shop-floor employees would cost about £50,000, although this will depend on the number and scope of the peripheral devices and the complexity of the software required[42,43].

Table 1 SERCK AUDCO performance record

From Reference 39

1 Year	2 Net despatches £m	3 Value added £m	4 Average number employed	5 Total wages and salaries £m	6 Despatches per employee £	7 Value added per employee £	8 Average income per employee £
1961/62	2.220	1.615	1001	0.714	2218	1613	714
1962/63	2.184	1.580	952	0.706	2294	1660	742
1963/64	2.585	1.872	903	0.752	2863	2073	833
1964/65	2.922	2.007	941	0.844	3105	2133	897
1965/66	3.363	2.303	992	0.951	3390	2320	953
1966/67	3.768	2.646	987	0.979	3818	2681	992
1967/68	3.576	2.519	906	0.951	3947	2780	1050
1968/69†	4.984	3.117	1130	1.338	4411	2758	1184
1969/70*	6.047	3.310	1175	1.625	5146	3242	1385

†During this period the progress in column 7 was retarded by the problems associated with the transfer of £1.3m of ball valve production to Newport.
*Based on 10 months—actual year ending 26 September 1970.

Terotechnology

Terotechnology, a term for 'preventive' or 'planned' maintenance, is claimed to be an area where considerable cost savings can be effected. One organisation that uses the computer typically to scheduled preventive maintenance is the CEGB: they used the computer available rather than purchase a new small one. However, what has been done on the ICL 1905 in the Midlands Region could have been done on a small computer—a complete system to provide preventive maintenance activities schedules. The system can produce work order cards and plant history catalogues, it can be integrated into a management information system (MIS), for cost and resource utilisation analyses.

Industrial R & D

A fascinating use of the small computer is that in a mobile instrumentation laboratory. An application (terminated September 1972) by the British Non-ferrous Metals Research Association[44] combined studies of process control, design and quality assurance of die-casting machines. A mobile Ferranti Argus 500 computer was taken to foundries where measurements were obtained on pressures, piston and metal movements, and metal and die temperature. The computer collected, analysed and obtained stress data. During the injection stroke of the die-casting machine, 4,000 readings were taken and put directly into store for subsequent processing during the slow part of the cycle. The total cycle time was about a quarter of a minute. One long-term aim was to study the feasibility of reactive control on various parts of the cycle, using the flexibility of the computer to explore ideas which would ultimately be carried out in production with much simpler control devices.

The Cranfield Unit for Precision Engineering also produced a mobile computing system based on a Marconi-Elliott 903 computer (an 8k core, 18 bit word length), a paper tape reader, paper tape punch, teletype and digital graph plotter, a general-purpose interface, 12 input/output channels multiplexed to the computer and a real-time clock. This machine was intended for shop-floor use to optimise digital servos and calibrate machine-tool slideways. Sussex University has developed a fully automated photoelastic stress analysis system[45] using a Minic mini-computer which permits a substantial gain over manual data collection, programs can be stored on a low cost data store mini file which can be sorted and loaded from conventional tape cassettes. Another recent example is that of the Ford Motor Company and Queen Mary College which have produced a computer-controlled engine test bed[46] using a General Automation SP16-45 mini-computer with 16K core store to monitor up to 22 parameters on each of six diesel or petrol engines simultaneously. The system is programmed to halt the test if pre-set limits are exceeded, thereby saving expensive prototypes. Engine characteristics can also be analysed automatically.

These four examples are sufficiently varied to demonstrate the usefulness of the small computer in enabling hitherto unattainable R & D to be done. They have in common the real-time monitoring measurement of working parameters and their analysis.

Industrial noise

Industrial applications occur in generally more severe environments than scientific applications; for example the factory environment may cause severe implementation problems for solid-state electronics due to electrical noise[47]. Some of the interface problems for industry have been described by Groves[48] and White[49]. They point out that facilities are often required to control equipment in plants which are separated by considerable distances, that industrial noise can be significant, and that the design requirements include high levels of reliability and protection. Groves suggests that the hardware design criterion to minimise noise should be that noise be eliminated after it has passed through a circuit—attenuation is not enough. Other electrical requirements are modularity, flexibility and versatility. Modularity is obtained by a range of plug-in logic modules identical with those in the computer. The cost of having to screen solid-state electronics may be significant in systems design.

Software for small computers

The software available for small computers apart from the essential assembler is generally the IFIPS sub-set of ALGOL, ASA FORTRAN IV, ASA Basic FORTRAN and 'CORAL 66'. Apart from those supplied by the older-established manufacturers, like DEC, IBM, ICL and Honeywell, few applications packages are readily available. Redac Software Ltd has specialised in producing packages for small computers ranging over a number of topics. Documentation is very important and can be taken as a measure of a manufacturer's standing.

The common small computer language seems to be tied up with the development of time-sharing, pointing towards JOSS-type languages like BASIC and FOCAL (DEC) for high level work and CORAL 66 for systems work and which has been used extensively for process control[27]. Applications software is rarely available for small computers because the computers themselves are relatively recent in origin, also economics may not permit manufacturers of relatively cheap machines to develop, supply and support extensive standard software. Furthermore the variety of applications and configurations tends to militate against standard packages. The functions of a small computer cover DDC (direct digital control), supervisory control, sequence control, data acquisition, operator communication and computation, for which are needed basic support, operating system and applications software. With regard to the latter, in the event of his supplier failing him, the industrial newcomer can obviously either write his own program to solve particular problems, use a bureau, or purchase an existing program. The lesson for both the user and the computer manufacturer is to choose the organisation that has the most to offer. It has been remarked that 'Mini-computers are not supported. They are abandoned'. This is not a view taken by some UK manufacturers[50].

As an application orientated machine the small computer is often likely to be too small to support a higher level language compiler, moreover the particular application such as CNC may not permit the slowness of the higher level software operation.

NEL has adopted the practice of developing software on a larger machine, the UNIVAC 1108, writing in a higher level language such as FORTRAN, and then translating back into assembler language. This is a practice recently advocated by Webster[51] who suggested that the higher level programming can be translated back into any small computer assembler language. Webster's article also contains a useful table of small computer data as do references [52] and [53].

Future trends

It is always comforting to find one's predictions coming true. All predictions for small computers in increased production, reduced costs, improved availability and reduced prices made three years ago have come true. It is therefore with more confidence that I had hitherto possessed that I turn again to a Delphi Long-range Technological Forecast made in 1970–71 by the Birniehill Institute at NEL and referred to in my paper in the *Production Engineer*[19].

The most imminent effects of the small computer were seen to be in the creation of data banks of information—assume that the mini-computer was envisaged as an I/O device. In the early 1980's a considerable increase in computerised design activity can be expected—I wonder how far we can foresee stand-alone systems of small size in this context, a trend towards using centralised bureaux such as at CADC and NEL might be more realistic? The correspondence between increased automation and process control, machine-tool technology and assembly and social problems, appears obvious and has been remarked on elsewhere. Man machine interaction was vaguely predicted as increasing in sophistication—a safe and obvious statement. As we ascend the time scale the subjects become more interesting perhaps but less predictable. I was surprised to see automated storage and materials handling placed so late as 1991 when so much has already been done in this respect.

Generally speaking the survey said that the more obvious

day-to-day processes are most likely to receive computer attention but as the software and intellectual tasks get harder they get further from us. The fully automated factory is seen to be so far away from common usage as to be outside the scope of prediction. Anything beyond the 1980's would be suspect.

The overall theme is piecemeal achievement of integrated manufacturing systems in the early years with greater system integration later on. There is the suggestion that the next generation of engineers will need to be very conversant with computer applications technology and perhaps there is a minor industrial evolution in being already. It would be interesting to see data on this subject. The reason that OR is not universal after more than a quarter of a century of serious work may be that data has not been readily available for analysis.

One of the most important predictions of this forecast was that there will be problems of unemployment and displacement consequent upon automation becoming critical in the mid 1980's. The most ready solution to this problem is seen as new types of employment as well as new methods of work and hence considerable retraining will be necessary.

It is evident in production engineering that there will be a demand for systems engineering knowledge, an ability to direct simulation analysis, for a broad inter-disciplinary background, for ability to invest and to apply innovation for profit and for an understanding of control, of the nature of trainable systems, adaptive and iterative processes. Computer-aided instruction using small machines with back-up stores may well prove useful in educating and training production engineers particularly when dealing with mass communications where there is also the demand for instruction tailored to individual or small group needs. Kiefer and Straber[54] suggest that process computers will become one of the most important teaching aids at engineering colleges in the future.

Blake[50] of Honeywell Information Systems commenting on the future of mini-computers pointed to the decreasing cost of mini-computer hardware and quoted an IBM VP 'With a mini-computer central processor now $5,000 in a system at $50,000 it puts the CP into the noise level or error range of cost estimating' and then, in asserting that the cost to a user of implementing a system is not decreasing yet as it should, said that the mini-computer manufacturers will need to devote a lot more attention to making their products more usable by their general customers.

Blake sees the current mini-computer as evolving in two distinct variations:

(*a*) one will become more oriented to problem-and-package deals, offering a user a quicker and easier way to do his job. It will offer much more high level software than at present, and the other

(*b*) specifically for the OEM produced by the semi conductor manufacturers.

Both variants are seen as offering memory addressability versatile I/O and much better high level features.

Nowadays management methodology is as precise as the manufacturing process itself. By this I mean that the accuracy of the computation is as free from error as the component produced on a machine tool (say), both being output from a device which manufactures to instructions—errors in computation are due to incorrect data or to unsatisfactory logic or algorithms; rarely are they due to the computer failing. In hardware, errors are again either humanly inserted (in the drawing office say) or due to machine wear or failure. But the precision of the computer method is becoming well known and the methodology that goes into it is ceasing to be the preserve of the management scientist. The prosperity of the firm and the nation will depend upon production engineers understanding and applying the methods of computer-aided manufacture and management. All levels of management—shop floor, board and those in-between—are concerned. The control support group or bureaux service that is needed to use these methods might be comprised of production engineers, management-scientists and economists behaving in an inter-disciplinary manner.

No detailed comment has been made on the industrial relations aspects of automation and in particular the increased use of small computers on the shop floor. A useful general statement by Sadler[55] suggests that, whilst the numbers of people involved tend to reduce as automation increases, their tasks call for more creative thought and initiative which are outside mechanistic controls. Interesting parallel confirmatory evidence is evolving from group technology practice, in which small computers can be used for production flow analysis, where job interest and worker morale seem to be enhanced from working in a machine-tool cell comprising a number of functionally different machines. Some likely consequences of computer usage have been suggested, the most important of which appears to be significant movement of workers to other jobs in the early nineteen eighties. Within the firm the ratio of personnel engaged on services, such as computer operations, is likely to increase. It should be expected that some of the drift of workers will be from manufacturing processes to computer services as representing an increasing trend in service industry activity.

Conclusions

In this review I have tried by examples to demonstrate the usefulness of the small computer in the automation of management activities. In the course of applying a broad treatment I have drawn up a comprehensive list of references from which further detailed case histories are available. I have also pointed to existing advisory services in the UK such as ERA, NCC, AERE, CADC and NEL, consultants and small computer manufacturers and universities such as Brunel and the Polytechnic of Central London; the wealth of UK expertise is impressive. Experience shows that mechanisation requires ordered collection of correct data and a delineation of the methodology used in the firm. It is likely that new applications of small computers will need a precursor methods study by production engineers; most computing organisations offer this as a service. Creation of data banks can be as formidable a task for small computers as for large machines.

The importance of the small computer as a front end device to a larger computer lies in its ability to do some local computation and data handling as well as acting as a data collecting and transmitting device; it can act as a multiplexer and as a data logger.

There is little published literature on the relative costs of using small computers versus manual systems or large computers. Kottler and McGill[56] have attempted a relative analysis of using small versus large for problem solving and have concluded with caution that computational costs can be reduced by a factor of 80 to 100 by running certain types of programs on mini-computers rather than large scale systems. The sample program chosen was a simulation of a two-dimensional time-dependent hydrodynamic model used to investigate transport and distribution of pollutants with an estuary and using finite-difference techniques. It is not very typical of industrial applications where the computational context is relatively small and the EDP high but it is near to design applications.

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This paper was to have been the last in the series. However, since starting the series, we have received a paper about a new computer language. This language is called EUCLID II and it can be used by an engineer to describe drawings in a format suitable for input to a computer. We feel that this paper might prove of practical interest to engineers and that it is worth extending the series to include it. It will be published in the December issue of the journal.